THE USE OF DOE-2 IN THE *HOME ENERGY SAVER*

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EXECUTIVE SUMMARY

The space-conditioning calculation section of the *Home Energy Saver* utilizes the building energy simulation program DOE-2.1E. DOE-2 macros are employed extensively to calculate input quantities, convert input quantities to the correct formats, and select the correct lines of conditional DOE-2 code for each house simulation. Many components of the house description can be varied, including:

- Weather data;
- Materials and constructions;
- Doors;
- Windows and skylights;
- Foundations;
- Attics and roofs;
- House geometry;
- House shading and buffering;
- Internal loads;
- Infiltration and natural ventilation;
- HVAC systems; and
- Ducts and pipes.

Inputs and outputs are passed to and from the DOE-2 code by the surrounding Web programming.

In the future, EnergyPlus could be substituted for DOE-2 in the *Home Energy Saver*.

1. INTRODUCTION

The *Home Energy Saver* (LBNL 2003) is a World Wide Web site devoted to residential energy analysis. The space-conditioning calculation section of the *Home Energy Saver* utilizes the detailed hourly building energy simulation program DOE-2.1E (Birdsall et al. 1990). User inputs for the energy-related characteristics of houses are collected and interpreted by Web programming outside of DOE-2 (Pinckard et al. 2003). The prepared data are then passed to a master DOE-2 Building Description Language (BDL) file (Winkelmann et al. 1993a) through macro input variables (Winkelmann et al. 1993b). These and other macro variables internal to the DOE-2 BDL file are used to calculate input quantities, convert input quantities to the correct formats, and select the correct lines of conditional DOE-2 code for each house simulation. DOE-2 output files are scanned by a second set of Web programming. The relevant output quantities are captured, converted and compiled, and returned for display on the Web (Pinckard et al. 2003).

The following report sections describe inputs to the DOE-2 model, the details of the model, and outputs from the DOE-2 model.

2. INPUTS TO THE DOE-2 MODEL

The DOE-2 macro input variables used in the *Home Energy Saver* are listed in Table 1, along with their definitions and possible values. Conditional variables are those used only when other variables have certain values.

3. THE DOE-2 MODEL

1.1. Weather Data

The 239 second-generation Typical Meteorological Year (TMY2) weather data files (Marion and Urban 1995), 42 first-generation Typical Meteorological Year (TMY) weather data files (NCDC 1981), and four California Climate Zone (CTZ) weather data files listed in Table 2 are accessible in the *Home Energy Saver*. Corresponding location and climatic data (U.S. DOE 1998) are also shown for comparison. Of these parameters, only the elevation is not automatically read from weather data files by DOE-2; its value must be input explicitly, as listed in Table 1.

1.2. Materials and Constructions

Table 3 shows the physical properties of the construction materials that can be modeled in the *Home Energy Saver*. The constructions comprised of these materials are listed in Table 4. Of special note are interior partition walls, floors, and ceilings, which are modeled as half-constructions and doubled in area to account correctly for radiative heat transfer between interior surfaces.

Foundation constructions are handled directly in the DOE-2 BDL file. Two-dimensional response factors for all other constructions are precalculated using a program called WALFERF. These response factors are accessed and used by DOE-2 during simulation.

Surface roughnesses are used in the calculation of exterior air film coefficients in DOE-2. Table 5 shows the roughness codes (Winkelmann et al. 1993a) assumed for the exterior surfaces of the constructions listed in Table 4.

Home Energy Saver users can specify the relative shades of exterior wall and roof surfaces. The solar absorptance values assigned to these shades are shown in Table 6.

1.3. Doors

The nominal door types shown in Table 7 can be modeled in the *Home Energy Saver*. The U-factors for these door types are drawn from ASHRAE (2001a). Alternatively, users can specify customized door types by U-factor. These U-factors incorporate the exterior air film coefficient at ASHRAE winter design conditions, while DOE-2 calculates variable exterior air film coefficients according to the hourly weather data supplied. Therefore, the input door U-factors are adjusted in DOE-2 macros according to the equation

$$U' = 1 / [(1 / U) - (1 / h_o)] \qquad (1)$$

where

U = design coefficient of heat transfer for a door (Btu/h·ft^2·°F)
h_o = design exterior air film coefficient (Btu/h·ft^2·°F)
U' = coefficient of heat transfer for a door, excluding the effect of the exterior air film coefficient (Btu/h·ft^2·°F)

In accordance with the most up-to-date calculation, the design exterior air film coefficient is assigned a value of 5.112 Btu/h·ft^2·°F (Köhler 2002).

All doors specified in the *Home Energy Saver* are assumed to be 6.67 ft high and 3 ft wide.

1.4. Windows and Skylights

The nominal window and skylight types shown in Table 8 can be modeled in the *Home Energy Saver*. As with the doors, their properties are drawn from ASHRAE (2001a). Users can also specify customized window and skylight types by U-factor and solar heat gain coefficient (SHGC). The U-factors are adjusted in DOE-2 macros in the same way as those of doors. Because DOE-2 uses the shading coefficient (SC) as the measure of solar transmission through fenestration, the SHGCs must be adjusted in DOE-2 macros according to the equation

$$SC = SHGC / 0.87 \qquad (2)$$

where

SHGC = whole-window or whole-skylight solar heat gain coefficient (dimensionless)
SC = whole-window or whole-skylight shading coefficient (dimensionless)

1.5. Foundations

Slabs-on-grade, unconditioned and conditioned basements, and unvented and vented crawlspaces, with and without insulation, can be modeled in the *Home Energy Saver*, as shown in Table 10. Mixed or "averaged" foundation types cannot be simulated. Basements are assumed to be 8 ft high, with 1 ft above grade for standard basements and 4 ft above grade for raised basements in split-level houses. Crawlspaces are assumed to be 2.5 ft high and entirely above grade.

Foundation heat transfer is simulated according to the method first devised by Huang et al. (1988) and subsequently updated (Winkelmann 1998; Huang 2003). This method utilizes effective foundation U-factors and fictitious foundation insulation layers to account for the insulating value of the surrounding soil. The effective U-factors for the foundation types modeled in the *Home Energy Saver* are included in Table 10.

1.6. Attics and Roofs

Unconditioned attics, conditioned attics, and cathedral or vaulted ceilings can be modeled in the *Home Energy Saver*. Mixed or "averaged" attic/roof types cannot be simulated.

Roof apexes are always modeled parallel to the long axes of houses. Only one skylight type can be modeled per roof.

1.7. House Geometry

Figure 1 indicates the necessary input dimensions for the eight types of house floor plans that can be modeled in the *Home Energy Saver*. Figure 2 provides further insight into the variety of house floor plans that can be treated.

Different wall, door, and window types can be modeled on different sides of houses. However, there is no provision for modeling mixed types on the same side.

Door and window areas are divided proportionately among the wall elements on a given façade. Window areas are also divided proportionately among the stories of a given façade. To avoid incorrect shading of doors and windows by one another, doors are always anchored at the left edges of walls, while windows are centered in walls. Window areas extend the full height of stories, resulting in offsetting errors in shading by other surfaces and objects.

Interior wall areas are taken to be half as great as conditioned floor areas, exclusive of basements and attics.

1.8. House Shading and Buffering

House shading by roof eaves, patios, carports, trellises, and similar overhangs can be modeled in the *Home Energy Saver*. Different extensions can be specified on different sides of houses. All overhangs are positioned at the roof line and assumed to run the lengths of the façades from which they extend. They are assigned a uniform solar transmittance of 0.

DOE-2 test simulations were performed to ascertain the buffering effects of a garage on different sides of a small, single-story house in different climates. Reductions in heating and cooling energy consumption of 1.5% were consistently obtained. These effects should be even less for larger houses. Because estimates of energy consumption from the *Home Energy Saver* are intended to be conservative, garages are not considered in the model.

Shade trees and neighboring houses can be specified independently on different sides of houses in the *Home Energy Saver*. Both are centered with respect to house façades. Trees are considered to have 6-ft-tall trunks, assigned widths of 15 ft, and positioned 10 ft away from the houses they shade. Neighboring houses are assigned the same widths as the houses they shade and positioned 20 ft away. Trees are assigned a solar transmittance of 0.70.

1.9. Internal Loads

House occupants are assumed to release sensible and latent loads of 230 Btu/h and 190 Btu/h, respectively, in the *Home Energy Saver*. Internal gains from appliances and lights are passed to DOE-2 from elsewhere in the *Homer Energy Saver* (Pinckard et al. 2003). Gains from appliances are assumed to be 80% sensible and 20% latent. The typical load profiles plotted in Figure 3 apply to all 365 days of the simulated year.

1.10. Infiltration and Natural Ventilation

The Sherman-Grimsrud Method (Sherman 1980; Winkelmann et al. 1993b) is the specified infiltration calculation option in the *Home Energy Saver*. Terrain parameters for suburban environments are used. Fractional leakage areas (FLAs) for conditioned spaces above grade are selected outside of DOE-2 according to user-specified house airtightness, vintage, and number of stories (Pinckard et al. 2003) and passed to DOE-2 through a macro input variable. Alternatively, users can specify measured or estimated air leakage rates. These leakage rates are converted to SI units in a DOE-2 macro according to the simple relationship

$$Q_{50} = 0.0004719474\ Q_{50ip} \tag{3}$$

where

Q_{50ip} = conditioned house envelope air leakage rate at 50 Pa (ft^3/min)
Q_{50} = conditioned house envelope air leakage rate at 50 Pa (m^3/s)

Conditioned house envelope air leakage rates are then found using the equation

$$Q_4 = Q_{50} (4 / 50)^{0.65} \tag{4}$$

where

Q_{50} = conditioned house envelope air leakage rate at 50 Pa (m^3/s)
Q_4 = conditioned house envelope air leakage rate at 4 Pa (m^3/s)

Effective leakage areas (ELAs) of conditioned house envelopes are determined using the equation

$$ELA = Q_4 / [4 (2 / \rho)]^{0.5} \tag{5}$$

where

Q_4 = conditioned house envelope air leakage rate at 4 Pa (m^3/s)
ρ = air density (1.2 kg/m^3)
ELA = effective leakage area of a conditioned house envelope (dimensionless)

Lastly, ELAs are converted to FLAs, including a unit conversion, using the relationship

$$FLA = (ELA / 0.09290304) / A_f \tag{6}$$

where

ELA = effective leakage area of a conditioned house envelope (dimensionless)
A_f = conditioned house floor area (ft^2)
FLA = fractional leakage area of a conditioned house envelope (dimensionless)

For simplicity, basements are assumed to have no air exchange with the exterior. Unvented and vented crawlspaces are assigned FLAs of 0.0015 and 0.0030, respectively. Unconditioned attics are assigned FLAs of 0.00242 (Treidler 1993).

The opening of windows for natural ventilation is simulated whenever the exterior temperature and humidity would result in a cooling effect. One quarter of the total user-specified window area is assumed open, and a discharge coefficient of 0.6 is applied.

1.11. HVAC Systems

The HVAC system types shown in Table 11 can be modeled in the *Home Energy Saver*. Performance curves for equipment efficiency as a function of part-load ratio are drawn from

Henderson et al. (1999). Curves for equipment capacity and efficiency as functions of outdoor temperature are unpublished LBNL derivations based on commercially available equipment performance data.

Hot water heating is simulated in DOE-2 for tankless and indirect boiler types. The results for system types simulated as other system types are converted after capture in the Web programming as necessary.

Window-mounted air conditioners that are controlled manually (i.e., by on-off switches rather than thermostats), whole-house fans, portable fans, and portable electric resistance heaters are treated separately from DOE-2 as appliances (Pinckard et al. 2003).

1.12. Ducts and Pipes

A simplified estimate of duct delivery efficiency, based on draft ASHRAE Standard 152P (ASHRAE 2001b), is currently used in the *Home Energy Saver*. This single numerical value is a weighted average corresponding to the pre-estimated annual heating and cooling loads for the house to be modeled. The development of a DOE-2 function for the hourly calculation of duct efficiency, based on the same Standard, is proposed.

Boiler pipes are simply treated. Uninsulated and insulated pipes are assigned delivery efficiencies of 0.90 and 0.95, respectively.

4. OUTPUTS FROM THE DOE-2 MODEL

Table 12 provides a brief description of the outputs captured from DOE-2 simulations in the *Home Energy Saver*. Hot water heating results are captured for tankless and indirect boilers.

5. FUTURE WORK

In the future, EnergyPlus could be substituted for DOE-2.1E as the space-conditioning energy calculator in the *Home Energy Saver*. This conversion would allow the simulation of such innovative HVAC systems as ground-source heat pumps, evaporative coolers, and hydronic radiant heating and cooling systems.

6. ACKNOWLEDGMENT

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7. REFERENCES

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 2001a. *ASHRAE Handbook: 2001 Fundamentals*. Atlanta, Georgia: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). 2001b. *Method of Test for Determining the Design and Seasonal Efficiencies of Residential Thermal Distribution Systems.* ASHRAE Standard 152P. In preparation. Atlanta, Georgia: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Birdsall, B., W.F. Buhl, K.L. Ellington, A.E. Erdem, and F.C. Winkelmann. 1990. *Overview of the DOE-2 Building Energy Analysis Program, Version 2.1D*. LBNL-19735, Rev. 1. Berkeley, California: Lawrence Berkeley National Laboratory.

Henderson, H., Y.J. Huang, and D. Parker. 1999. *Residential Equipment Part Load Curves for Use in DOE-2.* LBNL-42175. Berkeley, California: Lawrence Berkeley National Laboratory.

Huang, Y.J. 2003. In preparation. *Building Energy Simulation User News.*

Huang, Y.J., L.S. Shen, J.C. Bull, L.F. Goldberg. 1988. "Whole-House Simulation of Foundation Heat Flows Using the DOE-2.1C Program." *ASHRAE Transactions* 94(2): 936–944.

Köhler, C. 2002. Personal communication. October 10.

Lawrence Berkeley National Laboratory (LBNL). 2003. *Home Energy Saver.* World Wide Web site: http://HomeEnergySaver.lbl.gov.

Marion, W., and K. Urban. 1995. *User's Manual for TMY2s*. TP-463-7668. Golden, Colorado: National Renewable Energy Laboratory.

National Climatic Data Center (NCDC). 1981. *Typical Meteorological Year User's Manual.* TD-9734. Ashville, North Carolina: National Climatic Data Center.

Pinckard, M.J., R.E. Brown, J.D. Lutz, M.M. Moezzi, and E. Mills. 2003. *Documentation of Calculational Methodology and Input Data for LBNL's* Home Energy Saver *Web Site.* LBNL-51938. In preparation. Berkeley, California: Lawrence Berkeley National Laboratory.

Sherman, M.H. 1980. *Air Infiltration in Buildings.* LBNL-10712. Berkeley, California: Lawrence Berkeley National Laboratory.

Treidler, B. 1993. Personal communication.

U.S. Department of Energy (U.S. DOE). 1995. *House of Straw*. DOE/G010094-01. Washington, D.C.: U.S. Department of Energy.

U.S. Department of Energy (U.S. DOE). 1998. *EnergyPlus*. World Wide Web site: http://www.eren.doe.gov/buildings/energy_tools/energyplus/. Accessed December 2002.

Winkelmann, F.C. 1998. "Underground Surfaces: How to Get a Better Underground Surface Heat Transfer Calculation in DOE-2.1E." *Building Energy Simulation User News* 19(1): 6–13.

Winkelmann, F.C., B.E. Birdsall, W.F. Buhl, K.L. Ellington, A.E. Erdem, J.J. Hirsch, and S. Gates. 1993a. *DOE-2 BDL Summary, Version 2.1E*. LBNL-34946. Berkeley, California: Lawrence Berkeley National Laboratory.

Winkelmann, F.C., B.E. Birdsall, W.F. Buhl, K.L. Ellington, A.E. Erdem, J.J. Hirsch, and S. Gates. 1993b. *DOE-2 Supplement, Version 2.1E*. LBNL-34947. Berkeley, California: Lawrence Berkeley National Laboratory.